

GIS BASED DECISION SUPPORT SYSTEM FOR EFFICIENT WATER MANAGEMENT IN SONE CANAL COMMAND AREA

MASOOD AHMAD¹, NIRMAL KUMAR² & L. B. ROY³

¹Department of Civil Engineering, Maulana Azad College of Engineering and Technology, Patna, Bihar, India

²Department of Civil Engineering, M. I. T. Muzaffarpur, Bihar, India

³Department of Civil Engineering, N. I. T. Patna, Bihar, India

ABSTRACT

A GIS based Decision Support System (DSS) for efficient water management in Sone Canal Command Area (Bihar, India) is developed to estimate the real time water demand in distributaries. The DSS dynamically links the Water Balance Model with the canal network created in the GIS environment to predict the field irrigation requirements for the irrigated area by a distributary. The system allows the interactive selection of distributary and estimation of water demand for each distributary over the entire network of canal. For the estimation, model uses the historical weather data, weather forecast and distributary level information on crop and soil conditions. Patna Main Canal Command Area which is a part of the Sone Irrigation System is selected for the formulation of problem. The developed DSS provides a powerful tool for the overall management strategy to be adopted in the command area of the irrigation project by water resource planners and manager, particularly in the event of a shortfall in water supplies due to deficient monsoon.

KEYWORDS: Canal Supplies and Demand, Command Areas, Decision Support System, Irrigation Management, Irrigation Requirements, GIS, Water Balance Model, Water Management

INTRODUCTION

In India most of the major irrigation command areas suffer from problems of inadequate and unreliable water supply, having wide gaps between irrigation potential created and that being utilized. This leads to temporal imbalance of water demands and supplies, excessive seepage losses and rise of ground water table, resulting in problems of water logging and salinity. In addition, failure of monsoon rains aggravates the problems and results in water scarcity and drought which lead to disputes among the water users. All these problems exist due to inadequate attention paid to the assessment of water resources, non-matching of canal water releases with rainfall, crop water requirements and change in the cropping pattern from what has been envisaged at the time of planning. While short-term imbalances between water supplies and demands are inevitable, it is possible to reduce these considerably, if not totally, through development and adoption of appropriate water-management techniques and policies that take into account rainfall, changing cropping pattern and crop water demands. Almost all the current canal water-release policies in India are supply-based and make little effort in meeting the actual water requirement of the existing cropping pattern and under actual level of ground-water exploitation.

The operation of large canal irrigation system is a complex task. In the major irrigation system of India, water is delivered over a large area (10,000 to a million hectares or more in India) with spatially variable soils, crops and weather

conditions. The irrigation supplies reach the fields through a hierarchical network of main canals, branch canals and distributaries. The distributary is usually the last point of control for main irrigation system management as down-stream of this level, irrigation is either field-to-field or under the direct control of the farmers. The irrigation supplies into each distributary are decided based on the estimated water demands of the crops in the area irrigated by it, after accounting for field-application losses. The demands depend on soil, weather and crop conditions in the irrigated area. Further, the total areas irrigated by different distributaries also vary. The irrigation demand estimation for each distributary is, therefore, independent of other distributaries. The individual distributary-level water demands are aggregated to assess irrigation supply requirements at branch canals and main canals levels of the irrigation system after accounting for transmission losses. The operational efficiencies depend on the extent to which the irrigation supplies match the demands at each hierarchical level of the network. Thus estimating periodically, and in real time, the water demands of individual distributaries of the canal network are critical for improving the overall operational efficiencies of large irrigation system.

A basic operational problem faced by irrigation managers is the estimation of irrigation requirements at the level of each distributary at the beginning of every irrigation cycle. The difficulty lies in obtaining quick, systematic and realistic estimates of the demand in real time for different distributaries in the canal network in the presence of spatial variations in weather, soil and crop in the areas irrigated by them.

To increase operational efficiencies, variable irrigation supplies need to be matched in real time with the variable irrigation requirements over space. Modern spatial data management tools like Geographic Information Systems (GIS) can effectively include spatial variability of soil, crop, water supply and environment in dealing with the complex problems of water resources management.

The present study develops a scheme for providing a GIS-based decision support tool for irrigation system managers to assist them in making such estimates. It is shown that the features of GIS for storing, manipulating and analyzing spatial data related to soil, crop and weather can be used to provide an effective information system for the project area that is interactive and representative of the hierarchy of irrigation system operation, and give real time, systematic and quick estimates of irrigation demands in the distributaries taking-off from different canals/branch canals. Further irrigation demand prediction models are integrated with current season information on weather, weather forecasts and local information on crop and soil in a GIS environment. Since the distributary is the basic unit of decision making in the operation of the canal system, it allows quick estimation of the spatial variations in irrigation requirements in different distributaries that form the canal network, by interactively selecting them in the GIS.

STUDY AREA

The study area covers the Sone Irrigation Project (Figure 1& 2) in Bihar, India. The Sone project is a river diversion scheme built across the river Sone. It lies at latitude $24^{\circ} 48'N$ and longitude $84^{\circ} 07'E$. The total catchment area of the river is 71,259 sq. km, of which 17,651 sq. km lies in Bihar. The river is a tributary of the river Ganga. The project irrigates about 4, 00,000 ha

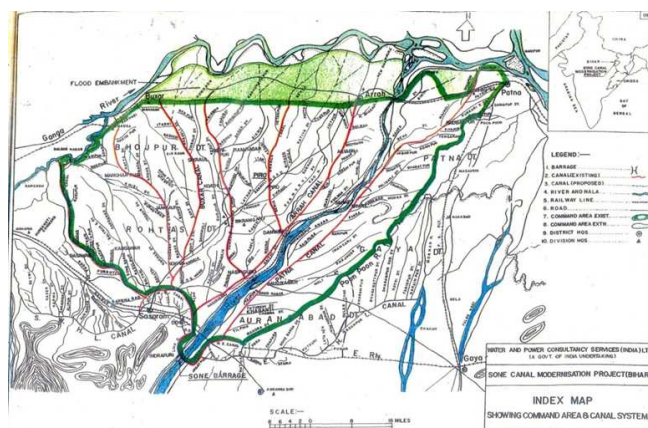


Figure 1: Index Map of Sone Command Area

during the monsoon (kharif season) and 1, 75,000 ha during the Rabi (winter season). The area receives about 1100 mm of rain, over 80% of which occurs over the monsoon season (June to September). Soils are alluvial and vary from light to heavy- textured clays in the top layer with coarse substrata. Almost plain in topography, it uniformly slopes towards the Ganga River. All these aspects make the area ideal for irrigated agriculture. Rice is the main crop grown in the area in the Kharif (monsoon) season and wheat in Rabi season. Crops other than rice occupy less than 2% of culturable command area (CCA). Sugarcane is the only cash crop grown in the area. Linseed and mustard oilseeds are also grown in Rabi season over a small area. The irrigation system has been operative since 1871 but irrigation in an organized manner started in 1879. The canal network consists of main canals and several branch canals (Patna Canal, Arrah Canal, Behea Branch Canal, Dumraon Branch Canal, Buxar Canal, Chausa Branch Canal, and Gara Choubey Branch Canal). Each branch canal has a network of several distributaries (tertiary canals) and minor distributaries or minors.

To meet the increasing demand of the water for irrigation, augmentation of irrigation resources was thought by the Government. As such a barrage of 1410 m length was constructed in 1968 at Indrapuri. This has 60 bays in the spillway portion each having width of 18.3 m and 9 bays under- sluices with identical spans (4 on the eastern and 5 on western side) and link canals on both side i.e. Eastern Sone link canal (ESLC) and Western Sone link canal (WSLC) to connect the old Sone Canal System, renamed as Eastern Low Level Canal (ELLC) and Western Low Level Canal (WLLC). Further on the eastern side, Patna Canal took off from ELLC and Arrah Canal, Bihea Branch Canal, Dumaraon Branch Canal, Buxar Branch Canal, Chausa Sub Branch Canal and Gara Choubey Branch Canal from WLLC on western side. The canal head-regulator (HR) had four gates on the eastern side and 7 on western side with a clear span 7.62 m each. The low level canal system was suitably remodeled to cater the need for the increased demand of the system.

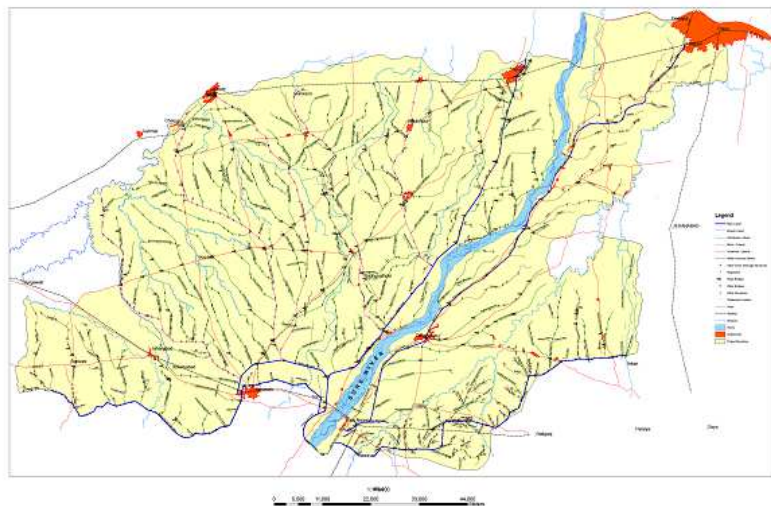


Figure 2: Satellite Map of Sone Command Area

For the formulation of problem, Patna Main Canal which forms a part of the Sone Irrigation Project in Bihar, India (figure 3) is selected which extend over 70 km and irrigates nearly 1, 90,000 hect through a network of 40 distributaries. The area is bounded by the river Sone on the west, river Punpun on the east and the river Ganga in the north. The area irrigated by each distributaries range from 200 to 25,000 hectare. The distributaries operate 10 days on and 5 days off cycle during Monsoon (Kharif) season. As per the information received from Water Resource Dept. Govt of Bihar (India), during the Monsoon (Kharif) season, the Patna main canal opens on 25th May and closes on 25th October.

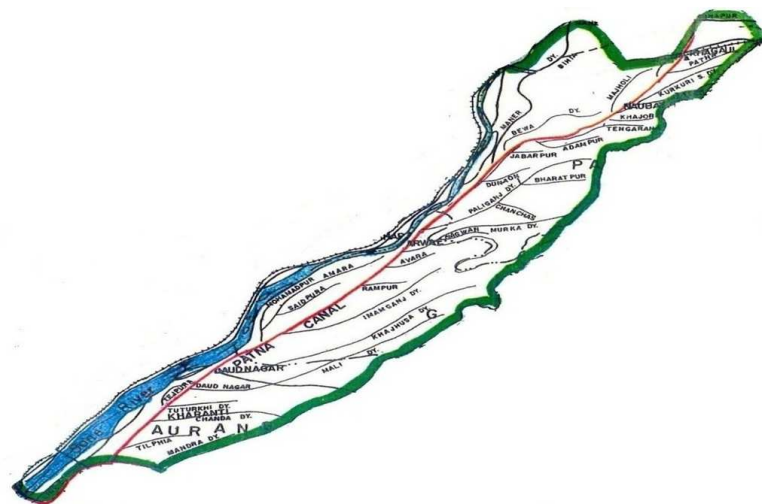


Figure 3: Patna Main Canal Command Area

METHODOLOGY

Decision Support System

The Decision Support System (DSS) is an integrated assembly of models, interpretive routines and other relevant information that efficiently processes input data, runs the models and displays the results in an easy-to interpret format. It is user friendly, which incorporates knowledge and expertise within the framework of decision support mechanism. Three fundamental components of DSS architecture are:

- The database (or knowledge base)
- The model (i.e., the decision context and user criteria), and
- The user interface.

Thus DSS helps the user to analyze the facts and situations, to try out several different scenarios and helps in selecting the most appropriate decision.

DSS is commonly used in the field of water resources management where decision makers have very diverse goals and values, including environmental, economic and ecological interest. Following technologies are generally used for decision making in water management:

- Simulation and Optimization Models
- Geographic Information System (GIS)
- Expert Systems
- Multi objective Analysis Tools

In the present study, only GIS technique is used for developing Decision Support System as GIS has capabilities to integrate database, statistics, maps with advance graphics for visualization and analysis. Spatial database such as soil, rainfall, geology, land use, transportation, topography, demography and socio-economic can be implemented for better decisions in water resource planning and management. With this powerful capacity for management and analysis of spatial data, GIS becomes an important tool in irrigation management.

Digitization of Map of Study Area

Digitization is the process of making features one can see the image editable and making them features to which additional spatial and non-spatial attributes can be assigned. This makes the feature as digital version of object that has an attribute table associated with them.

For digitization of Patna Main Canal, the Car to sat satellite map of Sone Command Area (Figure 2) prepared by National Remote Sensing Centre ISRO, Dept. of Space, Govt of India, Hyderabad is downloaded from BHUVAN (www.bhuvan3.nrsc.gov.in). The downloaded Patna Main Canal map (Figure 3) with its 40 distributaries is digitized using Esri Arc GIS version 10.1. In this case the distributary is treated as the basic unit of the GIS. All the relevant design data, i.e. name of distributary, design discharge, cultivable command area, reach of main canal, chainage length, nearest raingauge stations, dominant soil type etc. are added as attribute data (Table 1) in the form of layers in the GIS. The corresponding data for each distributary is automatically identified when selected in GIS. The digitized maps with attributes are shown in Figure 4 & 5.

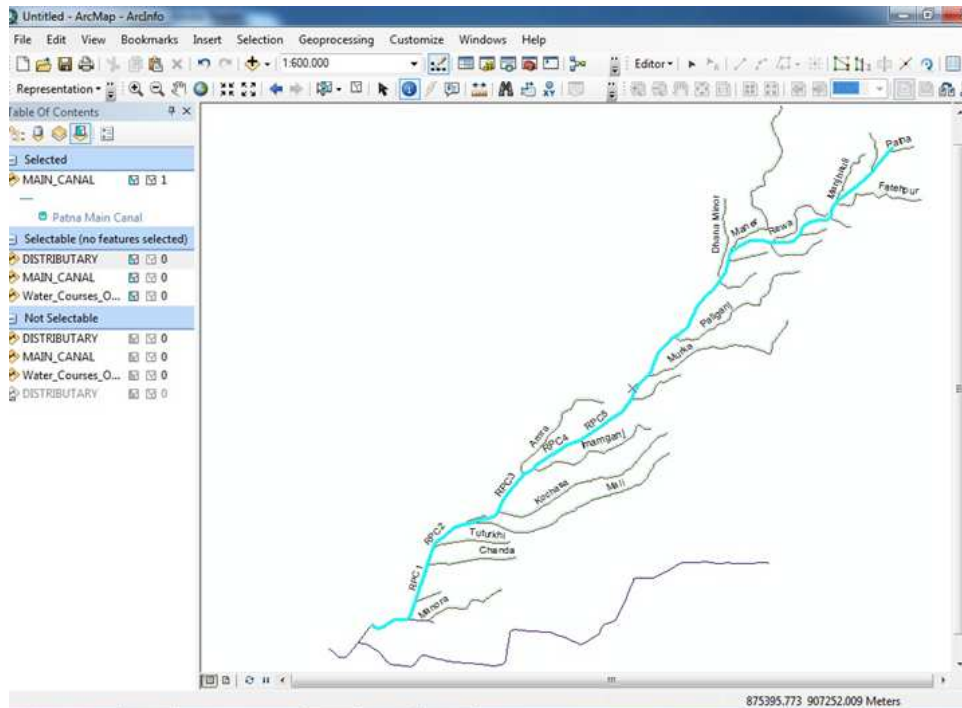


Figure 4: Digitized Patna Main Canal with its Distributaries

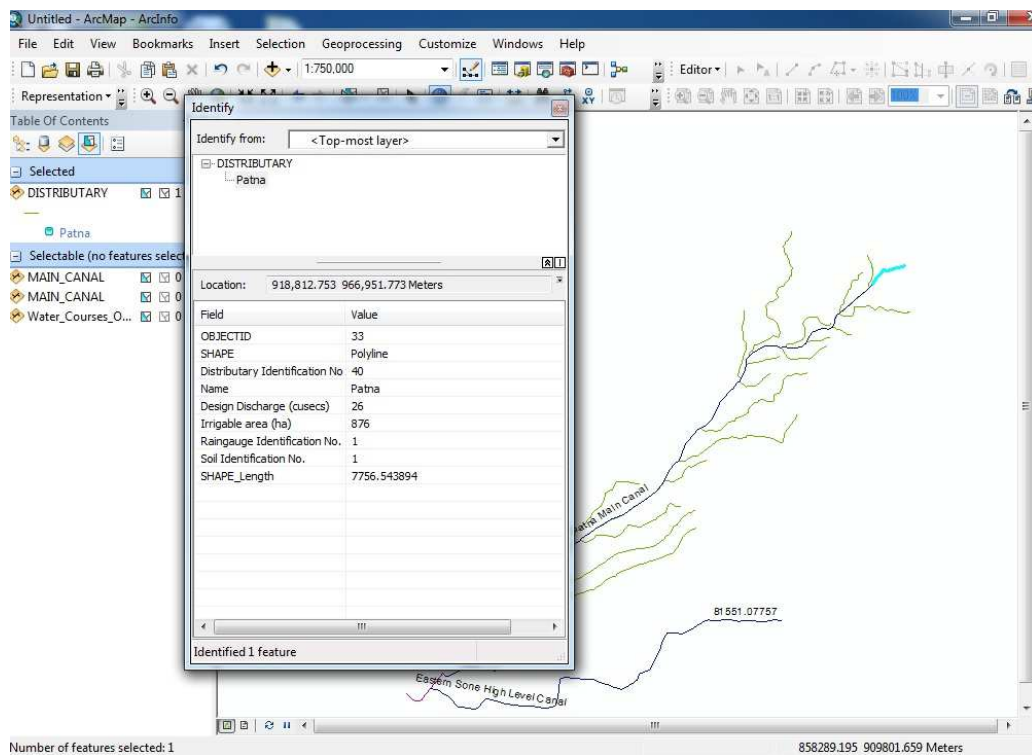


Figure 5: Digitized Selected Patna Distributry with Full Attributes

Table 1: Attribute Data of Distributaries of the Patna a Canal System

Distributary Identification No	Name	Design Discharge (cusecs)	Irrigable Area (ha)	Rainuage* Identification No	Soil* Identification No
1	Manorma	139	4695	2	1
2	Teldiha	60	2029	2	1
3	RPCI	24	817	2	1
4	Tejpura	24	800	2	1
5	Tejpura feeder	17	575	2	1
6	Chanda	191	6465	2	1
7	RPC2	18	605	2	1
8	LPCI	0	0	2	1
9	Tuturkhi	113	3838	2	1
10	Mali	387	13118	2	1
11	Ancha feeder	37	1265	2	1
12	Kochasa	588	19904	2	1
13	RPC3	15	505	2	1
14	Amra	210	7106	2	1
15	Imamganj	167	5671	2	1
16	RPC4	5	180	2	1
17	LPC2	8	273	2	1
18	RPC5	8	286	2	1
19	LPC3	8	260	2	1
20	R. Chauram	83	2816	2	1
21	Aiyara	144	4887	2	1
22	Murka	272	9216	2	1
23	RPC6	0	0	1	1
24	LPC4	0	0	1	1
25	Paliganj	360	12197	1	1
26	RPC7	0	0	1	1
27	Dorwa	131	4436	1	1
28	RPC8	0	0	1	1
29	Dhana Minor	10	319	1	1
30	Jwarpur	0	0	1	1
31	Maner	784	26547	1	1
32	Adampur	97	3270	1	1
33	Rewa	115	3904	1	1
34	Tangrila	31	1050	1	1
35	Khajuri	44	1485	1	1
36	Fatehpur	317	10741	1	1
37	Manjhauli	69	2337	1	1
38	Kurkuri	88	2962	1	1
39	Danapur	126	4263	1	1
40	Patna	26	876	1	1

- Data from two rain gauges are used. Rain gauge 1 is at the tail end of the Patna Canal and Rain gauge 2 is near its headwork. Data for only one soil type are used, as the soils in the case study area does not vary significantly. However, the DSS software is sufficiently general to deal with such variations.

Water Balance Model

The generalized Water Balance Model will be governed by following equations:

$$[DW]_t = [DW]_{t-1} + [RFV]_t + [IW]_t - [ET]_t - [P]_t - [Q]_t \quad \dots \quad (1)$$

Where,

[DW]_t = Depth of water in the field at the end of day

[DW]_{t-1} = Depth of water in the field at the beginning of day

[RFV]_t = Rainfall during the day

[IW]_t = Irrigation water applied in the field during the day

[ET]_t = Evapotranspiration during the day

[P]_t = Percolation during the day

[Q]_t = Runoff during the day

$$[Q]_t = [RFV]_t + [DW]_{t-1} - [BH] \quad (2)$$

Where [BH] = Bund Height

The above components are expressed in depth (mm) and the time period is considered as one day.

For solving the model, four crops namely Rice-1, Rice-2, Rice-3 and Rice-4 are taken, the transplanting date of each lags by one cycle i.e. 15 days and each crop covers 25% of command area. The rice transplanted on different dates needs to be treated as different crops for running the Water Balance Model as there are four transplanting dates. Duration of each crop is taken as 120 days. As per the general and agronomics practices for rice crop, at the transplanting date 150 mm water is applied and consequently if the depth of water at the beginning of any day is less than 10 mm, then on that day 50 mm irrigation water is applied to the field. On 45, 46 and 47th day from the day of transplantation, all water should be drained out from the field for efficient supply of nutrients to the crop and effective weed control in field. After 105th day, no water is applied to the field as this is the maturing period of the crops before harvesting.

The components of Water Balance Model for a rice crop are shown in Figure 6.

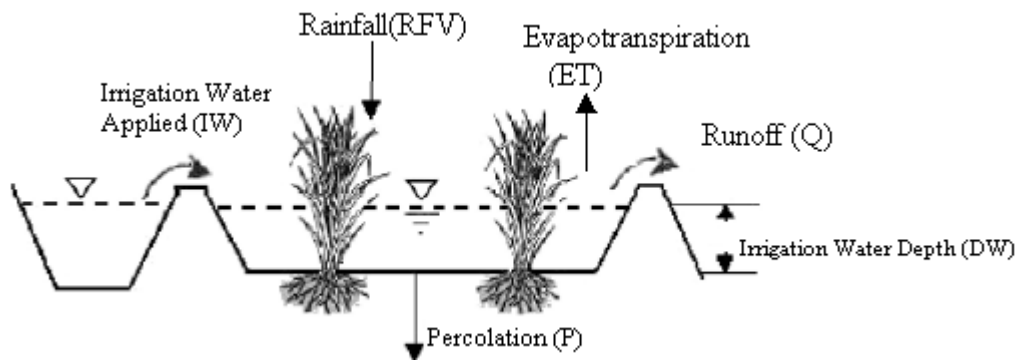


Figure 6: Water Balance Components of Model

The following input data are required for running the model:

- Name of the selected distributary
- Daily rainfall for each rain gauge station (mm)
- Forecast rainfall

- Transplanting date (day and month)
- Number of transplanting dates
- Crop duration (days)
- Bund height (mm)
- Days to cut-off date of irrigation
- Soil type

In Water Balance Equation, two components Evapotranspiration (ET) and Percolation Rate should be estimated. ET can be estimated by many methods ranging from the complex energy balance equation to simpler equations that require limited metrological data. According to Smith et. al. (1992); the Penman-Monteith method gives more accurate estimates of ET than other methods. Therefore, in the present study ET was estimated by Penman-Monteith equation using FAO CROPWAT 8.0 software.

For calculating ET, weather data of 50 years average (1951-2000) of study area were collected from IMD, Govt of India (www.imd.gov.in) and from the website of Weather & Climate (www.weather-and-climate.com). The climatological data for Patna is given in Table2.

Table 2: Climatological Data for Patna (50 Years Average)

Month	Min Temp °C	Max. Temp °C	Humidity %	Wind Speed m/sec	Sunshine Hours
Jan	9.3	23.0	63	1.7	9.3
Feb	11.6	26.1	57	1.7	9.0
March	16.4	32.4	37	1.7	9.3
April	22.1	37.4	34	2.4	9.7
May	25.1	38.4	49	2.4	10.6
June	26.7	36.7	66	2.4	7.7
July	26.1	32.9	78	2.4	6.0
August	26.1	32.5	83	2.4	6.7
September	25.3	32.2	80	1.7	7.0
October	21.6	31.7	76	1.7	9.0
November	14.8	28.9	60	1.7	9.3
December	10.1	24.6	66	1.7	9.0
Average	19.6	31.4	62	1.99	8.6

Source: IMD Pune and World Weather & Climate

The average monthly ET value in mm/day as calculated by CROPWAT 8.0 is given in Figure 7.

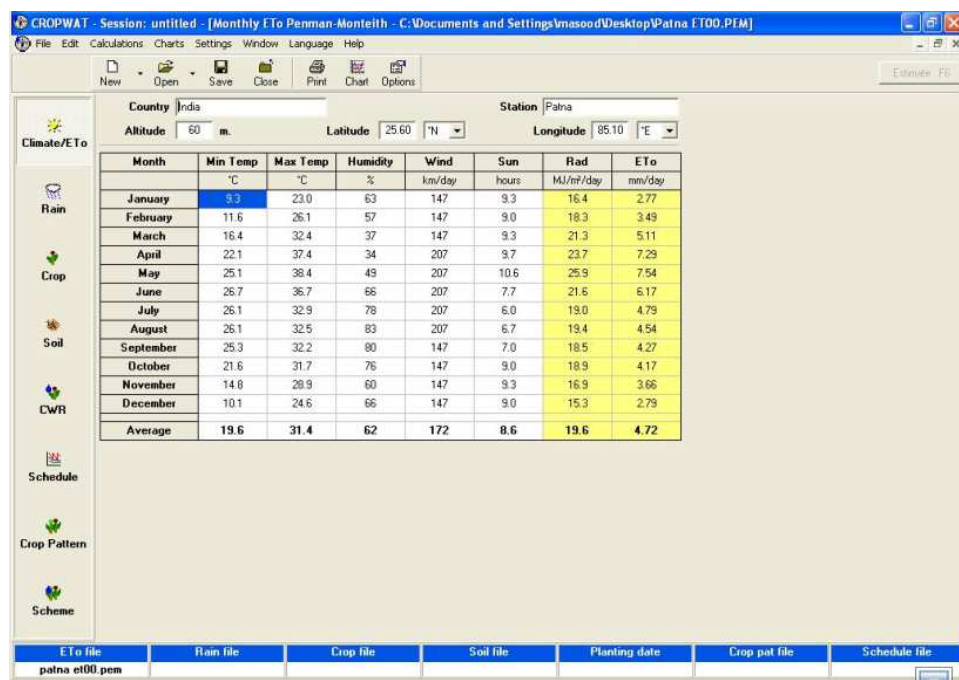


Figure 7: ET Calculation by CROPWAT 8.0

In our study, soil in the command area is almost identical as clay loam for which Percolation rate usually varies from 2-3 mm/day. In this study, the value of Percolation rate is taken as 2.2 mm/day.

For running the model, daily rainfall data of Patna of year 2008 is used as historical data of rainfall. The 5-7 days forecasted rainfall of IMD may also be used to get the irrigation water demand in advance in each cycle without any modification in the model, simply selecting the input file of forecasted rainfall.

Patna Distributary of Patna Main Canal System is selected for executing the model which has a command area of 876 ha.

GIS User –Interface Development

The Water Balance Model has been prepared in ArcGIS platform where background coding was done using Python Programming Language.

Following are the inputs which were used to calculate the sum of irrigation water (SIW) in each cycle such as:

- Daily Rainfall (RFV)
- Monthly ET
- Crop Types with DOT
- Soil Type with Percolation Rate data P

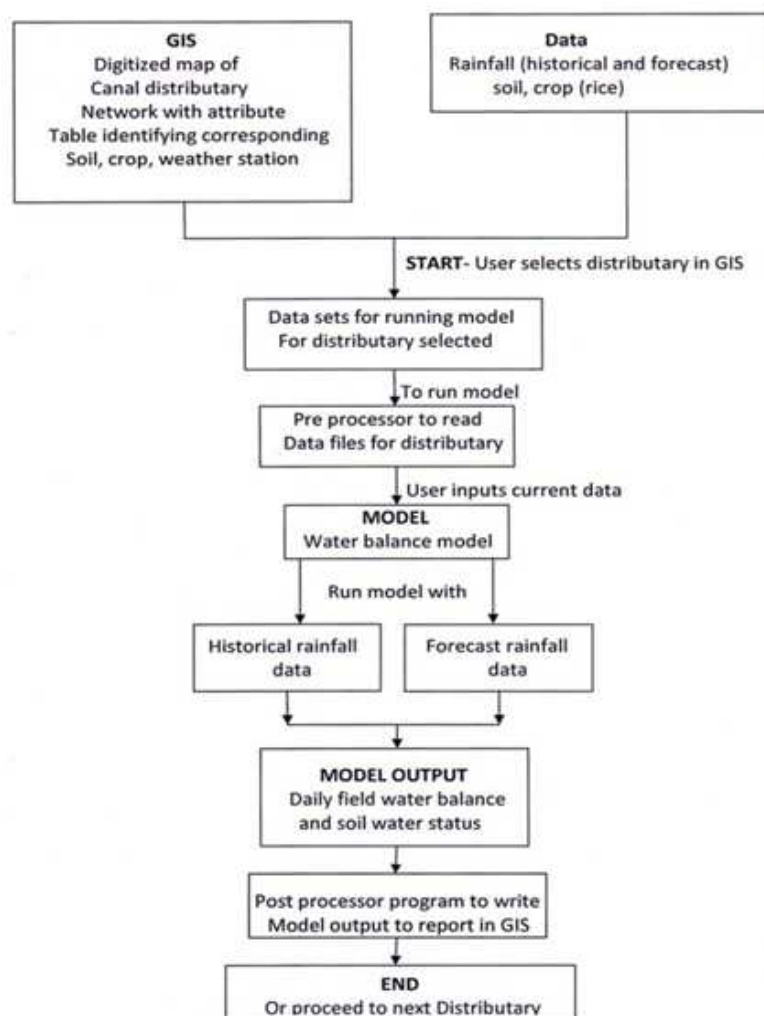


Figure 8: Dynamic User-GIS Model Linkages in Decision Support System

The GIS of the Patna Main Canal System and the Water Balance Model are finally dynamically linked for real time application in any season. This linkage allows:

- Selection of the distributary of interest on screen to identify the corresponding rainfall and soil data file.
- Running the Water Balance Model for each crop after selecting the transplanting date to screen queries.
- Preparing a report of the water status in fields in the command area of the distributary transplanted on different dates.
- Preparing the water release for the irrigation requirements at the head of the distributary.
- Proceed to next distributary.

The above steps are carried out sequentially within the GIS environment. The user need not at any stage come out of the GIS environment. Once the distributary is selected in GIS, the entire process is automated and made user interactive within GIS. The dynamic linkage flow chart is given above in Figure 8.

RESULTS AND DISCUSSIONS

Individual distributary can be selected by users from the GIS and reports of water status in fields and release can be prepared quickly. Once the distributary is selected, the model will run at daily time step with rainfall, soil and crops data to get the water status in field and required water release in each cycle. To illustrate the model, Patna Distributary of Patna Main Canal having 876 hect irrigable areas is selected and historical data of daily rainfall of Patna of year 2008 was used and result was shown in Figure 9. The model output gives the daily requirements of irrigation water to be supplied to each crop and then some of irrigation water required in each cycles (i.e. 15 days) is obtained. The differences in the water requirements in each cycle are due to the different magnitude of rainfall occurred during the different cycles and due to different amount of water required during the different stages of growth of the crop. The total quantity of water required for all the crops in each cycle varies from 0.34 cumec (11.93 cusec) to 1.32 cumec (46.58 cusec). This requirement has been compared with the design discharge of the Patna Distributary, which is 26 cusec.

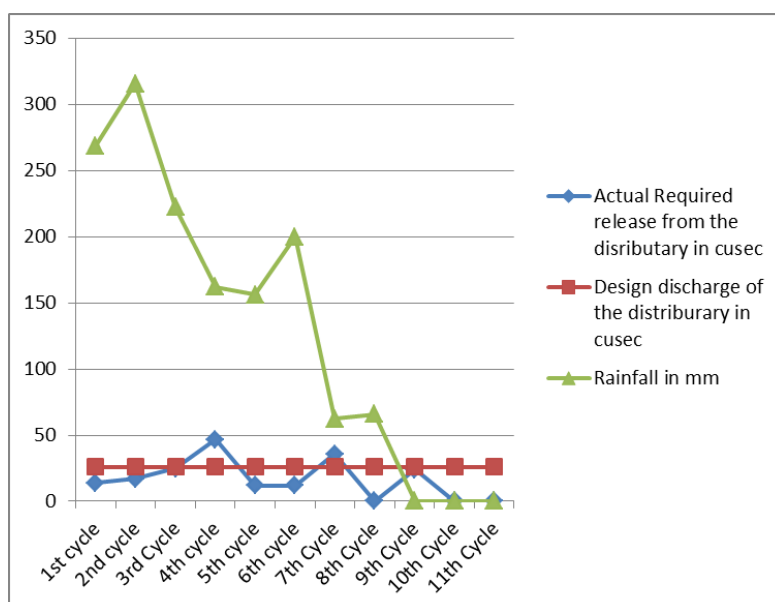


Figure 9: Required Irrigation Releases for Patna Distributary in Different Irrigation Cycle

The above results show that the demand of water varies significantly over the different irrigation cycles. In some cycle, demand is more than design capacity of the distributary, even though, in the year 2008 the rainfall was very good. In the low rainfall year, there will be more gaps in demand and availability of water in the distributary. In such periods, there may be a need to prioritize water allocations among the crops in the area irrigated by the distributary.

The same model is also to be run with the medium range forecasted rainfall to get the information regarding the water release requirement in each cycle in advance. The IMD usually provides medium range (5-7 days ahead) weather forecast. The use of this forecast will not alter the model development and application presented above in any way. The only change is to the input data of rainfall (forecasted data) instead of historical rainfall data.

The main problem faced by water resource managers is estimating demand at the head of the distributaries of the canal network in advance for each irrigation cycle. This is mainly because of spatial variations in weather and crop transplanting dates. It was shown in this study that water demand for any distributary can be estimated by linking dynamically the GIS of the canal system with a Water Balance Model and current season data of weather, weather forecast

and crop and soil conditions. The water resource managers can obtain the required information by simply selecting the distributary in the GIS. The developed DSS also allows the quick estimation of the variations in irrigation requirement in different distributaries that form the canal network and comparisons with the available channel capacities. Hence this simulation combined with strong agronomic knowledge and engineering judgment provides a powerful impact on the overall water management strategy to be adopted in the command area of the irrigation project.

CONCLUSIONS

Efficient management of irrigation systems involves appropriate water releases to match crop water requirements and control of seepage from the conveyance system for attaining higher application efficiencies. The developed GIS based Decision support system (DSS) dynamically linked with Water Balance Model can greatly assist to water resource managers in improving irrigation management strategy as this simulation helps in estimating the water releases required in each cycle in advance and with this knowledge the water can be conserved in the reservoir during low demand period and the same can be released during high demand period. Hence this study presents the strength of GIS user-interface technique to improve the decision making in the daily operation and management activities of irrigation water in allocations, releases and monitoring of distributions in the command area of the irrigation project.

REFERENCES

1. Allen R G, Pereira L S, Dirk R, Martin S. Crop Evapotranspiration; Guidelines for computing crop water requirements, FAO Irrigation and Drainage, Rome, 1998; Paper No-56.
2. Allen R G, Jensen M E and Burman R D, Evapotranspiration and irrigation water requirements, ASCE Manual and Report on Engg Practice, American Society of Civil Engg, 1990, 70 p- 123.
3. Alvankar R, Mousavizadeh M H and Nazari M, Application of GIS in water resources studies, Fourth Conference of Iranian Commission on Large Dams, Tehran, Iran, 200 p 30-37.
4. Amor V M, Das G A, Loof R, Application of GIS and crop growth models in estimating water productivity, Journal of Agricultural Water Management ,2002, 54 p 205- 225.
5. Chaudhary C D, Land evaluation by integrating Remote Sensing and GIS Technique for cropping system analysis in Jamui, Munger, Khagaria and Bhagalpur Districts of Bihar, Technical Report No. 102, Non Plan Research Project 2010-13, Dept. of Soil Science and Agriculture Chemistry, Bihar Agriculture University, Sabour, Bihar.
6. Doorenbos J and Pruitt W O, Crop water requirements, Irrigation and Drainage Paper No.24, FAO, Rome, Italy, 1977.
7. Eduardo A H H, Jose L A, Antoneuta R and Vital P S P, GIS supported farm irrigation system design and planning, Journal of Water Resources and Irrigation Management , 2012,1 p 7-14.
8. George B A, Reddy B R S, Raghuvanshi N S and Wallenger W W, Decision support system for estimating reference evapotranspiration, Journal of Irrigation Drainage, Engg Div. 2002,128 p 1-10
9. Goundogdu K S, Degirmenci H and Demirtas C, Creation of GIS supported database in irrigation project management, AGROENVIRON 2002, Cairo, Egypt, 2002, 26- 29 October.
10. Lin W T, Fong H Y and Ming S, GIS for irrigation management, Irrigation Associations National Taiwan

University Taipei, 2004, p D1- 71.

11. Mckinney D C, Technical report on International Survey of decision support systems for integrated water management, Bucharest, Romania, 2004.
12. Mckinney D C and Cai X, Linking GIS and water resources management models: an object-oriented method, Elsevier, Environmental Modeling & software, 2002, 17 p 413-425.
13. Miles S B and Ho C L, Applications and issues of GIS as tool for Civil Engg modeling, Journal of Computing Civil Engg, 2001, 13(3), p 144-152.
14. Naidu C R and Giridhar M V S S, Geo-Spatial database creation for Wazirabad canal command area, Journal of Geographic Information System, 2011, 3 p 290-297.
15. Pervez M S, Interactive information system for irrigation management GIS and Remote Sensing Specialist, 2002, International Water Management Institute, p 1-12.
16. Ray S S and Dadhwal V K, Estimation of Crop evapotranspiration of irrigation command area using Remote Sensing and GIS, Journal of Agricultural Water Management, 2001, 49 p 230-249.
17. Sarangi A, Rao N H, Sheena M B and Singh A K, Use of GIS tool in watershed hydrology and irrigation water management, GISdevelopment.net/Application/Natural Resource Management, 2009, p 1-4.
18. Tan C H, Application of GIS in a web based query system for farmland irrigation in Taiwan, 2003, Agricultural Engg Research Centre, Taiwan, p 2-3.
19. Tsihrintgis V A, Hamid R and Fuentes H R, Use of GIS in water resources, Water Resource Management, 1996, 10 p 251-257.
20. Walsh M R, Toward spatial decision support systems in water resources, Journal of Water Resource Planning & Management, 1992, 109(2), p 158-169.